A Redesign Methodology for Storage Management Virtualization

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Abstract—**The growth of business has escalated the need to employ information technologies services rapidly to support the mounting corporate activities. Each time a new service was needed; a new server along with the relevant software and storage elements was deployed. This situation has led to what is often referred to as the "server sprawl problem," where many underutilized servers with heterogeneous storage elements are inaugurated whereas the total operational cost is high. In this paper we propose a redesign methodology to address this problem by using virtualization-based server consolidation and modeling servers' storage unification through storage area network (SAN). Our redesign methodology attempts to maximize the average servers' utilizations and ultimately to reduce the operational cost and to guarantee an acceptable level of performance. Extensive simulations to study the servers' utilizations and the performance have been carried out to validate the redesign tactic. The experimental results have revealed the efficiency of the proposed redesign method.**

Keywords—server sprawl; storage area network; unification; optimization; simulation.

I. Introduction

Over the last three decades, information technology (IT) businesses have grown, so did the need for the rapid deployment of its services in-order to support the expanding business undertakings. This IT growth was often implemented in ad hoc manners, where the introduction of a new service necessitated the deployment of a new physical server outfitted with the relevant service software and the corresponding acquisition of new storage elements. This has led to what is often referred to as the "server sprawl problem." It is a situation in which multiple underutilized servers with heterogeneous storage elements take up more space with high operational cost and consume more energy than can be justified by their workload. According to [1], the average use of server capacity is only 10-30% while the average utilization of a data center is less than 20%. Thus, such a situation incurs wasting resources, high investment and operational costs along with the difficulty of managing such a hybrid environment.

An architectural approach, which is becoming increasingly popular to address this problem, is known as server consolidation. It could be regarded as an extensive capacity-planning problem [2-4] utilizing virtualization technology. A different way to solve the server consolidation problem is through the combinational optimization theory as described in [5-8] and also to utilize virtualization. Although virtualization-based server consolidation has become the "go-to" solution to server sprawl problem; it has introduced new problems of its own. The advantages of this approach include the reduction of the required physical servers and the accompanying infrastructures, as well as increasing the resource utilization and thereby reducing the overall operational costs. However, the drawback arises in the service performance and storage limitation due to the fact that virtualization occurs both at the server and storage levels.

Our redesign methodology differs from the existing approaches, it is based on the concept of keeping virtual machines for hosting services only and deploying a storage area network (SAN) for storages unification. Our solution aims to reduce the number of servers and eliminate the shortages within the local disks. In this paper, we have formulated the server sprawl problem as an optimization problem, where the main objective is to maximize the average servers' utilization, while assuring an acceptable level of performance. Also, we have proposed a cost model to assess the investment and operational costs before and after applying the redesign methodology. We have utilized Simulated Annealing algorithm to search the redesign space and network simulator version 2 (NS-2) to assess the performance of the enterprise information network (EIN) before and after the redesign process. This paper represents continuous efforts to build-up on our previous redesign management experiences [9-13], where presently we contribute to shift from a network topology redesign into a network storage redesign. This area of redesign offers a great promise.

II. Background

SAN is a specialized, high-speed network attaching servers and storage devices. It allows multiple servers access to a pool of storages concurrently using interconnect elements. This segregation of data storage from the servers led to the ease of access of data directly from device to device without server intervention, thus it frees up computing cycles for business logic computations rather than data management tasks. Also, it allows storage and server resources to grow independently. Moreover, it eliminates any restriction to the amount of data that a server can access, currently limited by the number of storage devices attached to the individual server.

The term **virtualization** describes the separation of a resource for a service from the underlying physical delivery of that service. The virtualization in server consolidation describes a virtual machine; this virtual machine can serve multiple services by sharing hardware resources without interference so that a single physical server can run multiple operating systems and services at the same time. Apart from higher server utilization levels, the benefits are: reduced time for deployment, easier system management, and overall lower the maintenance and the operating costs.

Simulated Annealing (SA) algorithm is a general purpose meta-heuristic method that has been applied successfully to a number of optimization problems [14]. Due to the nature of recent problems in terms of complexity and the availability of high computing processing, SA is becoming a popular technique to solve such problems.

NS2, which has been developed by the Virtual InterNetwork Testbed (VINT) project [16], is one of the most major evaluation methodologies in computer network area. NS2 takes an object-oriented approach using C++ and OTCL; moreover, it is an open source code [16]. Thus, it allows designers to modify the built-in components or add their own designed components to carry out the certain functions.

III. Problem Formulation

We view the server sprawl problem as a service allocation problem, where the IT administrator needs to consolidate servers by assigning services to physical servers so as to maximize the resource utilization to ultimately minimize overall costs. We have formulated this problem as an optimization problem, where the main objective is to maximize the average resource utilization, while preserving the service level of performance. Additionally, a cost model is proposed to be used to validate the algorithm solution. The solution with minimum cost would be considered and accepted.

We are given $\boldsymbol{N}$ services, which are to be served by $\boldsymbol{M}$ servers. In this model, each server $\boldsymbol{j}$ has, an operation age in years $\boldsymbol{A_j}$, an average resource utilization value $\boldsymbol{U_j}$ and a maximum workload capacity $\boldsymbol{W_j}$ supported by server $\boldsymbol{j}$ to perform within accepted quality of service (QoS). Also, each service $\boldsymbol{i}$ has minimum resource requirements: storage memory capacity $\boldsymbol{k_i}$, resource utilization $\boldsymbol{S_i}$ and service level agreement $\boldsymbol{L_i}$ to assure QoS of service $\boldsymbol{i}$. Let $\boldsymbol{\mu_j}$ and $\boldsymbol{\beta_{ij}}$ be binary decision variables indicating which server is used and which service is allocated to which server respectively. Finally, let D be the SAN storage capacity needed to be deployed in the network. Considering all of that, the problem is formulated as following:

$$Max \sum_{j=1}^{M} \mu_j \times U_j \tag{1}$$

Subject to:

$$\sum_{j=1}^{M} \beta_{ij} = 1 \quad for\ i = 1,2..N \tag{2}$$

$$U_j = \sum_{i=1}^{N} \mu_j \times \left(\beta_{ij} \times S_i\right) < 100 \quad for\ j = 1,2..M \tag{3}$$

$$\sum_{i=1}^{N} \mu_j \times \left(\beta_{ij} \times L_i\right) \leq W_j \quad for\ j = 1,2..M \tag{4}$$

$$\sum_{i=1}^{N} k_i \leq D \tag{5}$$

The objective function (1) maximizes the server average resource utilization, while the first constraint (2) makes sure that all services are allocated to physical servers and each service is allocated exactly once. The second constraint (3) assures that the cumulated resource utilization of the services assigned to a physical server is within the accepted resource utilization threshold percentage. The third constraint (4) ensures that the aggregated workload of multiple services assigned to a physical server does not exceed the workload capacity of that server. The last constraint (5) ensures that the deployed SAN storage capacity satisfies the minimum storage capacity required by all the services in EIN.

A. Cost Model

Our cost model is proposed based on two general scenarios in server and storage consolidation tasks:

1) *Scenario 1: an existing utilization decision, the use of existing servers for the server consolidation.*In this scenario, the operational cost is a variable cost, which increases depending on the depreciation of the server. The coefficient $\boldsymbol{C_{oj}}$ represents the operational cost of server $\boldsymbol{j}$ for one year, which is increasing annually by a rate of $\boldsymbol{\alpha}$.Since there is no deployment cost in this scenario, then the operational cost $\boldsymbol{Cost_{ope}}$ of EIN is estimated in (6). Where $\boldsymbol{y}$ is the number of EIN operational years.

$$Cost_{ope} = \sum_{j=1}^{M} (\mu_j \times A_j \times \alpha \times C_{oj}) + C_{oj} \tag{6}$$

2) *Scenario 2: an investment decision, the information on how many new technologies of servers and SAN storage to buy and require for the given set of services.*In this scenario, the coefficient $\boldsymbol{C_j}$ represents the purchasing costs of a new physical server $\boldsymbol{j}$. Moreover, the coefficient $\boldsymbol{C_D}$ represents the cost of one gigabit of SAN technology memory. Both $\boldsymbol{C_j}$ and $\boldsymbol{C_D}$ are fixed cost and considered in the deployment year only. Therefore, the cost in the deployment year including the operation cost $\boldsymbol{Cost_{dep}}$ of EIN is estimated in (7), where x is the total number of new server deployed to the existing EIN.

$$Cost_{dep} = \left(x \times C_j\right) + \left(D \times C_D\right) + \left(Cost_{ope}\right) \tag{7}$$

B. Redesign Methodology

We describe the management decisions for the servers' consolidation and storages unification as follow:

1) Physical servers with unjustified high operational costs and low average utilizationis nominated for removal. For the given $\boldsymbol{M}$ servers, each physical server $\boldsymbol{j}$,which has an operation age $\boldsymbol{A_j}$ > 3and an average utilization $\boldsymbol{U_j}$ < 35%, is candidate to be removed from EIN.

*2) Physical servers with high operational cost and high average utilization is nominated to beremoved and replaced with new physical server.*For the given $\boldsymbol{M}$ servers, each physical server $\boldsymbol{j}$, which hasan operation age $\boldsymbol{A_j}$ > 3 and an average utilization $\boldsymbol{U_j}$ > 70%, is candidate to be removed and replaced with a new server.

3) Services associated with the removed physical servers must be allocated to physical server(s). For the given $\boldsymbol{N}$ services, each service $\boldsymbol{i}$ associated with the removed server $\boldsymbol{j}$ is allocated to physical server, which satisfies the minimum service resource requirements ($\boldsymbol{S_i}$ and $\boldsymbol{L_i}$).

4) Number of the new physical servers must be less or equal to the number of the removed servers.

5) Required storage memory capacity for all the services must be satisfied when deploying SAN technology.

We illustrate the proposed redesign methodology in Fig.1, where the design process starts with identifying the specifications of EIN with its servers and storages capacity including the services requirements and level of agreement. Next, the algorithm inputs and thresholds are considered. Then, we perform an NS-2 simulation to assess the performance of EIN. Afterward, we estimate the sum of cost to assess the utilization-cost effect and analyze the performance. Based on these analyses, a redesign process is executed with SAN consideration utilizing SA. The redesign loop can be executed several times until the utilization-cost effect with accepted performance thresholds is reached.

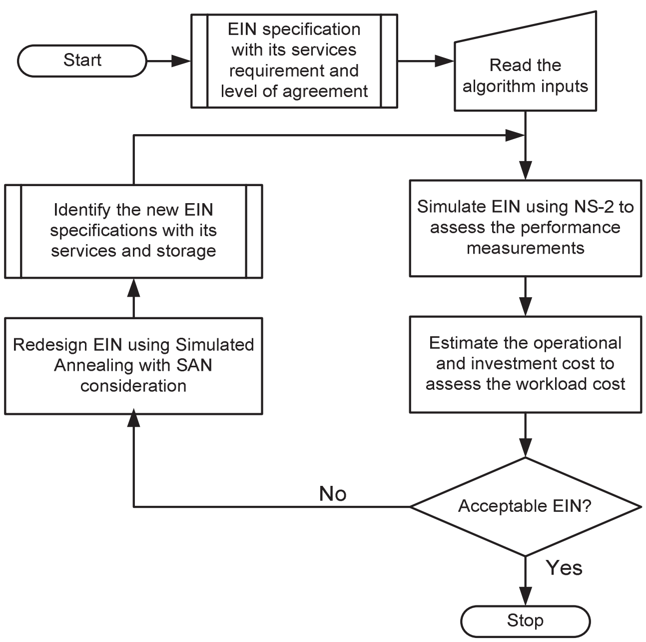

Figure 1. The proposed redesign methodology

IV. Experimental Results

A medium size EIN consists of 54 physical servers hosting 54 services and serving 680 clients that it used as our case study. The servers have different resource capacities and workloads, we used NS-2 and SA parameters setting similar to the one used in papers [2] and [16] respectively. Also, we assumed that $\boldsymbol{\alpha}$ = 20%, $\boldsymbol{C_j}$= \$10,000, $\boldsymbol{C_D}$ = \$5 for 1G, and $\boldsymbol{C_{oj}}$= \$1000 to calculate the initial/operational cost.

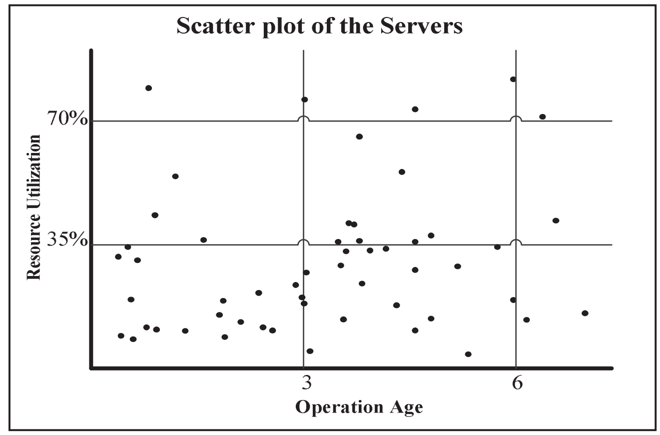

Figure 2. The servers' scatter plot in EIN before redesign.

TABLE I. Simulation Results of EIN Before Redesign

	Min	Max	Ave.
Resource Utilization	4.20%	81.22%	30.27%
Performance (#Requests/Sec.)	251	447	325

A. Given Enterprise Information Network (Before)

Fig. 2 shows a scatter plot of the servers based on their operation age ($\boldsymbol{A_j}$) and average resource utilization ($\boldsymbol{U_j}$) of the given EIN. A total of 28 servers with $\boldsymbol{A_j}$>3, and 37 servers with $\boldsymbol{U_j}$< 35% could be observed. The initial operational costs at year zero ($\boldsymbol{y}$ = 0) using (6) is \$91,200.Table I summarizes the NS2 results. It could be noticed that the average resource utilization is 30.27%, while 325 requests per second is the average performance of the services.

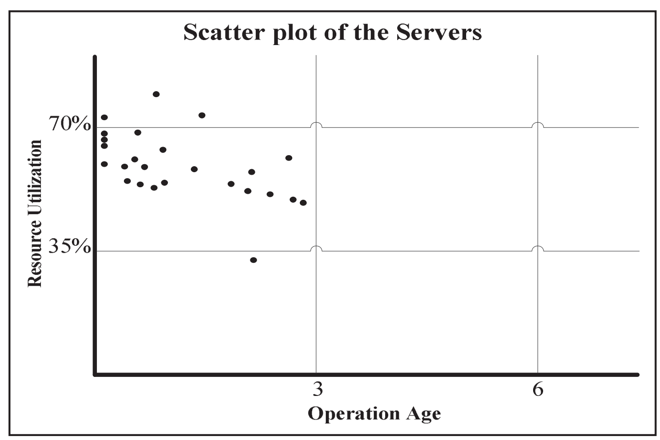

Figure 3. The servers' scatter plot of EIN after redesign.

B. Proposed Enterprise Enformation Network (After)

Our solution, from SA, consists of 25 physical servers hosting 54 services serving the 680 clients. A total of 5 ($\boldsymbol{x=5}$) new physical servers and a 10 Terabyte ($\boldsymbol{D=10T}$) of SAN storage capacity is deployed in the new design. The server scatter plot of the new EIN is illustrated in Fig.3, while Table II reveals the simulation results. Interestingly, only one server has $\boldsymbol{U_j}$< 35%. Additionally, we observed that the average resource utilization and the service level of performance have increased compared to the given EIN by 29.17% (59.48% − 30.27%) and 22.98% (((422 − 325) ÷ 422) × 100%) respectively.

TABLE II. SIMULATION RESULTS OF EIN AFTER REDESIGN

	Min	Max	Ave.
Resource Utilization	32.12%	87.23%	59.48%
Performance (#Requests/Sec.)	319	522	422

Using (7), the investment and operational costs for the proposed EIN is $125,800. We could observed that the cost of the proposed solution is higher than the cost of the existing EIN by $34,600 (= $125,800– $91,200) due to the fact that before we have $0 investment cost while after we have $100,000 ($(x \times C_j) + (D \times C_D) = (5 \times \$10{,}000) + (10000 \times \$5)$) investment cost. We utilized (6) and (7) to assess the return of this investment for EIN before and after for the next 5 operational years (Table III).It could be noticed that investing $34,600 would provide a return of investment of 36.58% (((709,200 – 449,800) / 709,200) x 100). Remarkably, the operation cost of the proposed EIN at year 5 is less than the operation cost of the existing EIN at year 0 by $10,400.

TABLE III. THE TOTAL COSTS FOR EIN BEFORE AND AFTER REDESIGN.

Operational Year	Costs		
	Before	After	Difference
0 (Investment)	$91,200	$125,800	-$34,600
1	$102,200	$48,800	$53,200
2	$112,800	$56,800	$56,000
3	$123,600	$64,800	$58,800
4	$134,400	$72,800	$61,600
5	$145,200	$80,800	$64,400
Total	**$709,200**	**$449,800**	**$259,400**

V. CONCLUSIONS AND FUTURE WORKS

In this paper, we have proposed a redesign methodology to solve the server sprawl problem by servers' consolidation and storages' unification. We addressed maximizing the average resource utilization while preserving the service level agreement towards reducing the operational costs. SA and NS-2 experiments' results showed that our redesign strategy could achieve an acceptable return of investment of 37% for 5 operational years. Also, our redesigned EIN improved the average resource utilization and services levels of performance which are increased by 29% and 23% respectively.

In future work, we plan to incorporate the operational cost in the objective function and include a measurement for the overhead incurred during the migration of virtual machines. Additionally, Tabu search will be utilized to validate our current methodology.

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